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(54) Title: METHOD AND APPARATUS FOR GENERATING A RADIO FREQUENCY SIGNAL
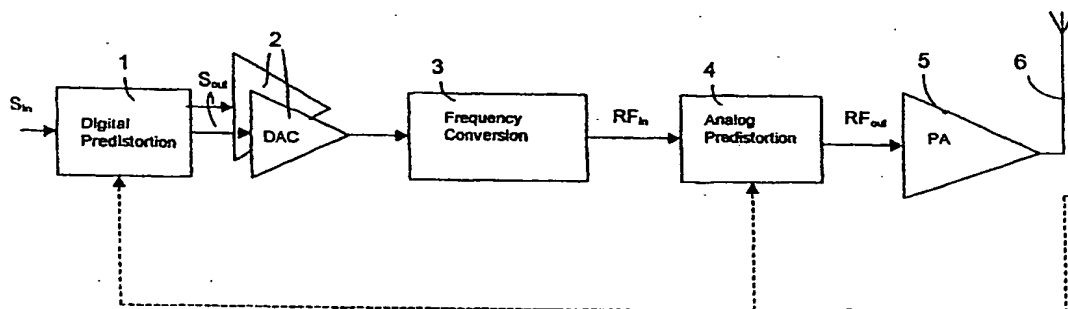
(57) Abstract: The invention relates to linearisation of a radio frequency (RF) power amplifier (5) by predistortion. Digital predis-tortion is performed (1) on received digitized base-band input signals to compensate for amplifier distortion. The resulting signal is converted to an analog signal via two D/A converters (2), after which analog frequency conversion is performed (3) on the analog signal to achieve a radio frequency (RF) signal. This radio frequency signal is exposed to analog predistortion (4) and thereafter amplified by the power amplifier.

Method and apparatus for generating a radio frequency signal.

TECHNICAL FIELD

The present invention relates to a method and an apparatus for
generating a radio frequency (RF) signal, and more particularly
to linear amplification of radio frequency signals.

BACKGROUND ART

In a radio base station, there is a need for a high power
amplifier in the transmitter section to provide each radio
channel with enough power to reach the outer limits of a cell
covered by a base station.

When using the same amplifier for simultaneous amplification of
several information signals modulated on different carrier waves
or when using linear modulation, such as QAM (Quadrature
Amplitude Modulation), high amplifier linearity is required.
This is because it is essential in this case to maintain all
phase and amplitude positions of the signal components involved
in the amplification. Otherwise inter-modulation will occur
between the signal components and the spectrum of the amplified
signal will broaden. Intermodulation distortion will interfere
with signals on other channels. Examples of systems, wherein
high linearity is required, are those in which several combined
narrow-band signals or wide-band signals such as CDMA need to be
amplified.

RF power amplifiers are inherently non-linear devices since they
generate unwanted intermodulation products, which manifest
themselves as spurious signals in the amplified output signal,
separate and distinct from the input signal. The distortion
introduced by an RF amplifier causes the phase and amplitude of

its amplified output signal to depart from the phase and amplitude, respectively, of the input signal.

There exist different methods for linearising amplifiers. An overview and reference list of linearisation methods, including Back-off of class A, Feedforward, Vector summation, Feedback and Predistortion Linearisation, is given in "Linearisation of RF Power Amplifiers" by Mark. A. Briffa, department of Electrical and Electronic Engineering, Victoria University of Technology, December 1996, Australia.

Predistortion is a method that modifies the original input signal to the power amplifier such that it is complementary to the distortion characteristics of the power amplifier. The cascaded response of complementary predistortion and amplifier distortion should therefore result in a linear response. Typically the complementary predistortion function is based on the approximation of the amplifier being modelled by a power or a voltera series (otherwise known as the AM/AM & AM/PM). However, the complementary predistortion function could also include higher order effects, such as thermal properties of the transistor and/or frequency dependent properties due to the bias and matching circuits. Predistortion can be applied at radioor Intermediate frequencies, known as analog predistortion, or applied at baseband, known as digital predistortion. Additionally, to achieve excellent linearity, adaption of the predistortion means is needed to circumvent changes due temperature, component ageing etc.

The predistortion mechanism may be made adaptive by extracting the error distortion signal component at the output of the RF amplifier and adjusting the predistortion means in accordance with the extracted error behaviour of the RF amplifier during real-time operation, so as to effectively continuously minimize distortion at the amplifier's output. A good overview of digital predistortion adaptive means is given in J. K. Cavers, "Amplifier linearisation by adaptive predistortion", US patent

5,049,832. International patent applications WO 99/45638 and WO
99/45640 provide examples of an analog predistortion adaptive
method.

To achieve good results with analog predistortion, careful
matching of the complementary predistortion function and
amplifier distortion function is required. However, analog
elements with excellent matching characteristics are very
difficult and expensive to produce. Analog predistortion
typically has a limited dynamic (operation) range and is
therefore only able to produce limited performance improvements.
Analog predistortion, however, can operate over large
bandwidths.

On the other hand, adaptive digital predistortion is able to
produce, in theory, the excellent matching properties required
to achieve significant improvements in linearity. However,
because the predistortion occurs at baseband, it needs to be
converted to radio frequency before it can be amplified. The
frequency conversion, however, takes place in the analog domain,
which by its nature destroys the perfect matching capabilities
of the digital domain. This results in that also digital
predistortion becomes limited in respect of performance and
bandwidth compared to analog predistortion.

The frequency dependent properties of the analog frequency
conversion process, amplitude ripple and phase ripple, are the
basic mechanisms for destroying the digital domain's matching
qualities. Both of these quantities are directly linked to the
amount of performance improvement that can be obtained. As the
amplitude and phase ripple quantities increase, the obtainable
linearity performance improvement becomes reduced, regardless of
how well matched the complementary function is in the digital
domain.

Analog and digital predistortion linearisation are typically
implemented as standalone techniques, because of practical

implementation problems arising from the fact that the two
solutions require different architectures for implementation.
This is best illustrated in the following two examples. In a
normal macro base station, the Power Amplifier (PA) is a module
that fits in one part of the rack, sometimes included with the
frequency conversion circuits. The digital base band processing
circuits physically reside in another part of the rack. These
two components are physically separated and the signals are
communicated via a coaxial cable. In a mast mounted antenna
application, the PA is at the top of the mast and the base band
processing part is at the base of the mast. In both examples,
the digital baseband processing parts and the PA module are
physically separated, which introduces practical implementation
problems.

However, there exist some examples of a combined linearisation
solution. For example the combination of digital predistortion
with feedforward is presented in WO 98/12800. The feedforward
architecture requires additional signal paths and two couplers,
one to acquire the signal out of the power amplifier (PA) and
the other one to subtract the remaining PA distortion. The last
coupler inserts a loss. This results in the overall efficiency
being degraded, also when combining the two methods. The
solution is also quite complicated, requiring a large amount of
components, making it difficult to implement.

Another example of combining RF predistortion with Feedforward
is described in the technology white paper, Multi-Carrier Power
Amplifiers join the Digital Revolution' Yuval Shalom, Fall 1999
issue of Site management and Technology Magazine, Intertec
Publishing. It states that the DC-RF efficiency of feedforward
amplifiers is limited to around 6-8% because of three factors.

1)   Large backoffs due to the large peak to average ratios of
      multicarrier (wideband) signals. The DC power supplied to
      the power amplifier is given by P_{DCamp}, and the RF output
      power from the amplifier is given by P_{RF}.

2)   Additional hardware such as delay lines and couplers after
      the power amplifier introduce insertion (power) loss. The
      power loss can be defined as a fraction of the total power
      surviving after the loss, typically 0.8 i.e 20% (1 dB) of
      power is lost.

3)   DC power consumed ($P_{DCother}$) by other parts of the feedforward
      system i.e. error amplifiers, control circuitry.

The DC-RF efficiency formula can be approximated for the
combined feedforward and RF predistortion system as

DC-RF efficiency = 0.8 * P_{RF}/($P_{DCother}$ + P_{dcamp})

In the case of a predistortion system only, there is no need for
the additional hardware that introduces losses in a feedforward
system. As regards the other parts of the feedforward system,
this reduces complexity and results in the DC-RF efficiency
increasing as shown below by the DC-RF efficiency formula for
predistortion:

DC-RF efficiency = P_{RF}/P_{Dcamp} > 0.8 * P_{FR}/ ($P_{DCother}$ + P_{Dcamp})

Wide band applications partly have to be designed with
architectures and solutions different from those of the narrow
band solutions because of different problems.

Predistortion is a quasi-closed loop power amplification system,
as opposed to a closed loop system. Closed loop systems are
based on feedback, i.e. cartesian feedback, envelope feedback,
polar feedback.

The advantage of quasi-closed loop systems is that both
narrowband and wideband systems of an order of magnitude of 10's
of MHz can be used. As opposed to this, closed systems are
limited to narrow band signals of an order of magnitude of 100's
of kHz for practical stability reasons, although they can

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usually achieve higher levels of linearisation than quasi-closed
loop systems.

In addition to quasi-closed and closed loop systems, feedforward
amplification can be used that can result in both high levels of
linearity and transmittance of wideband signals. As compared to
predistortion methods this requires a rather complicated gain
and phase tracking mechanism to keep the loops in balance and
results in low power efficiency. The feedforward architecture is
currently the most widely used technique for linearising
applications in wideband radio. For wideband radio applications,
predistortion, both analog and digital methods, in general is
characterized by good power efficiency, as compared to the use
of the feedforward methods, although they have lower linearity
performance than feedforward.

Digital predistortion has not been technologically possible to
use for wide band signals earlier with a sufficient performance
because of a relatively slow digital signal processing and
limited precision. The development of faster digital signal
processing by the introduction of e.g. digital circuit
fabrication methods, and advancements in DAC (Digital to Analog
Converter) technology, has, however, remedied this problem.

However, use of digital predistortion techniques in wide band
systems accentuates problems appearing in connection with
upconversion of the base band signal to a radio signal, since
the frequency dependent properties of the analog frequency
conversion process limit performance improvement.

The analog frequency upconversion process is usually assumed to
have the same transfer function regardless of frequency, viz.:

$$Y = f^n(X)$$

wherein Y is the output signal, and is a function of the input
signal X. Typically the frequency conversion circuitry is

designed such that Y is linearly related to X, and this
assumption is relevant to narrow band signals. In wideband
signal applications, the frequency upconversion process becomes
more dependent on frequency:

$$Y = f^n(X, frequency)$$

This frequency dependence destroys perfect digital predistortion
matching properties, and therefore limits the amount of
linearisation. The dependence on frequency can be reduced, but
it becomes expensive, if not impractical, to design over a wide
bandwidth with very low amplitude and phase ripple. That is, low
enough amplitude and phase ripple allowing digital predistortion
to achieve the desired level of linearity. A digital frequency
equaliser could be used to negate the frequency upconverter's
frequency dependence. However, there will always exist some
residual frequency dependence that limits the amount of
linearisation, and it will also increase the complexity of the
solution.

It is an object of the invention to provide an improved
linearisation method by using digital predistortion in both wide
band and narrow band applications, that will overcome the
frequency conversion problems in connection with digital
predistortion.

SUMMARY OF THE INVENTION

The method of the invention for linearisation of a radio
frequency (RF) power amplifier by predistortion, comprises the
steps of receiving a digitized base-band input signal, to be
amplified by said RF power amplifier,
performing digital predistortion of the signals to compensate
for amplifier distortion,
converting the signal to an analog signal via two D/A
converters,
performing analog frequency conversion to achieve a radio

frequency (RF) signal,
performing analog predistortion of the RF signal,
amplifying the analog predistorted signal by said RF power
amplifier.

The power amplifier of the invention is characterized by means
for performing the above steps of the invention. Alternatively,
the digitally predistorted signal could be converted to a low
digital intermediate frequency in the method and the power
amplifier of the invention, whereafter the signal can be
converted to an analog signal by using only one D/A converter.
Both of these solutions can also be used in such another
architecture of the invention, wherein the received base-band
input signal can be split into two signals of 90° phase
difference, whereafter the rest of the steps of the method
of the invention is performed for each of the signals.

In all embodiments of the invention, the predistortion can be
made adaptive to further improve the performance and/or
circumvent changes due to temperature, component ageing etc.

Furthermore, the invention can be used in connection with
different architectures described later.

The invention has several advantages as compared to prior
predistortion solutions. By solving the upconversion problems
caused by the digital predistortion process by splitting the
performance requirements between digital and analog
predistortion, improved linearity is achieved compared to
digital predistortion alone. The solution of the invention also
gives a higher efficiency compared to feedforward linearisation
techniques, especially for wide band systems.

The invention also has the advantage of reduced requirements on
frequency conversion parts since the linearisation performance
now partly is handled by the analog predistortion means. This
results in a cheaper frequency conversion solution.

The physical separation of the digital base-band processing
parts and the PA module in prior art solutions exemplified above
was one of the problems to overcome so that a combination of
analog and digital predistortion would be possible.

One of the merits of the invention also lies in the fact that
the overall performance improvement can be enhanced by splitting
it between digital predistortion and analog predistortion. For
example, if the basic amplifier gives a performance of -30dBc
and 30dB improvement is required, an overall performance of the
linearisation of -60dBc is needed. Then digital predistortion
could obtain an improvement of 20 dB and the analog
predistortion one of 10dB. This makes a total linearisation
solution possible, which is very difficult practically or
impossible to achieve with digital or analog predistortion
alone. For digital predistortion to achieve this alone would
require stringent design requirements on the frequency
upconverter resulting in either an impossible design
requirement or a very expensive solution. For analog
predistortion to achieve this alone would require excellent
matching of the complementary predistortion function and
amplifier distortion function, and analog parts with excellent
matching characteristics are very difficult and expensive to
produce.

Another merit of the invention is that it combines the natural
strengths of analog and digital predistortion. That is analog
predistortion has limited correction capabilities over a large
frequency range, whilst digital predistortion has excellent
correction capabilities over a narrower frequency range. The
combination can therefore yield improved correction capabilities
over all frequency ranges when compared to either digital or
analog predistortion techniques alone.

The invention will now be described more closely with reference
to the appended drawings on which:

Figure 1 is a schematic block diagram illustrating principles of
the invention,

Figure 2 shows a Doherty amplifier architecture according to
prior art,

Figure 3 shows an example of an embodiment of the invention as
implemented in the Doherty architecture,

Figure 4 shows an example of the digital predistortion part of
the invention more in detail,

Figure 5 shows an example of the the analog predistortion part
of the invention more in detail,

Figure 6 shows simulation results of a digital predistortion
method of prior art,

Figure 7 shows simulation results of the method of the
invention.

DETAILED DESCRIPTION

With reference to Fig. 1, a digitized complex baseband input
signal S_{in} is first predistorted, as indicated by block 1, to
produce a complex baseband digital predistorted output signal
S_{out}. More particularly, this is done in a manner to be
complementary with respect to a combination of an analog
predistorter and a power amplifier, discussed further below and
indicated by blocks 4 and 5, respectively. This combination of
an analog predistorter and a power amplifier can be thought of
as forming a linear power amplifier.

The complex baseband digital predistorted signal S_{out} is then
converted to an analog signal by two Digital to Analog
Converters (DAC), indicated at 2. Alternatively, although not
shown in Fig. 1, the baseband digital predistorted signal S_{out}
can be first digitally frequency converted, before being
converted to an analog signal via a single DAC.

The output from the DAC is then frequency converted by frequency
conversion circuits, indicated by block 3, to a radio frequency
signal RF_{in}. The frequency conversion circuits 3 can consist of

mixers, filters, amplifiers etc. arranged in a manner obvious to
a man skilled in the art. The frequency conversion process
introduces frequency dependent amplitude and phase ripple, that
partly destroys the linearisation ability that can be achieved
with digital predistortion alone. The signal RF_{in} containing the
frequency converted digitally predistorted signal, is now
exposed to analog predistortion as indicated by block 4, in a
complementary manner with respect to the power amplifier 5. The
RF predistorted signal, RF_{out}, is then passed through the power
amplifier 5 before being transmitted by an antenna 6.

The digital and analog predistorters 1 and 4, respectively, can
optionally be made adaptive to further improve the linear
performance and/or circumvent changes due to temperature &
ageing etc. The adaption operation, which can be carried out
with methods well known in art, is indicated by dotted lines
ended by an arrow at each one of the blocks 1 and 4 in Fig. 1.

Figure 2 schematically illustrates a so called Doherty
amplifier. The architecture of a Doherty amplifier is e.g.
described in "RF Power Amplifiers for Wireless Communications"
by Steve C. Cripps (ISBN 0-89006-989-1, Artech House, 685 Canton
Street, Norwood MA 02062). According to the basic concept of
this amplifier, two amplifier devices 5, 5' are used in parallel
and the final maximum RF output power is produced by the
combined power of both devices. The Doherty amplifier
constitutes an efficiency enhancement technique as compared to a
one amplifier device technique, but does not introduce any
linearisation improvements. In short, an incoming base band
signal S_{in} is quadrature split, indicated by block 7, into two
signals with 90° phase difference. The two signals are amplified
by the amplifier devices 5, 5', combined as indicated by block
15, and then transmitted by an antenna 6.

With reference to Fig. 3, the performance of the Doherty
amplifier can be improved with respect to linearisation by
introducing therein the solution of the present invention, as

described with reference to Fig. 1. The incoming base band
signal S_{in} is first split, indicated by block 7, into a first
signal S_{in} being identical to the input signal, and a second
signal $S_{in90°}$ being 90 degrees phase shifted. The 90 degree phase
shift can be implemented by the so called Hilbert Transform, or
according to other methods obvious to a man skilled in the art.

The two signals S_{in} and $S_{in90°}$ are processed in each a path
containing the same type of function blocks as in Fig. 1,
described earlier, said paths extending in parallel from block 7
to a combiner indicated by block 15. The top path blocks are
numbered 1, 2, 3, 4 and 5 as in Fig. 1, whereas the lower path
blocks are numbered 1', 2', 3', 4' and 5'. The top path,
receiving the original signal, includes the main power amplifier
5, whereas the lower path, receiving the 90 degrees phase
shifted signal, includes a peak or auxiliary amplifier 5'.

The output signals from the amplifiers 5 and 5' are combined in
the combiner 15 after the signal of the top path having been
shifted by 90 degrees. Typically, the combination may be
implemented as a quarter wave delay after the main power
amplifier 5 output. The combined output signal from the combiner
15 is then transmitted by the antenna 6.

Applying, as described above, the invention on the Doherty
architecture improves the linearity of the power amplifiers
used, and makes it more suitable for use in both narrow band and
wide band radio communication systems.

Figures 4 and 5 illustrate some simple examples of digital and
analog predistortion methods that can be used in connection with
the invention, assuming in these Figures that the amplifier is
memoryless. What is referred to is use of AM/AM (amplitude
modulation/amplitude modulation), AM/PM (amplitude
modulation/phase modulation) model of amplifier.

If the power amplifier is exposed to memory effects such as

caused by thermal properties of the power transistor and/or
frequency dependent properties due to the bias and matching
circuits, then it is obvious to a man of the art that the
digital and analog predistorters will also require memory to
compensate for these effects. An example of a digital and an
analog predistorter will now be described, that can be used in
connection with the combination of analog and predistortion
methods according to the invention.

Figure 4 illustrates an example of a method for implementing
digital predistortion of the kind referred to by block 1 in Fig.
1. The digital predistorter in this case is assumed to
compensate for the combination of the analog predistorter and
power amplifier with a memoryless non-linearity and is based on
cartesian complex gain predistortion. Other memoryless
predistorter examples could include polar complex gain or full
cartesian mapping, the principles of which are described in US
patent 5,049,832.

In Fig. 4, the complex baseband input digital signal S_{in} of Fig.
1 is received by an address generator 8. The address generator 8
generates an address based on a function of the amplitude of the
signal, this being consistent with the memory non-linearity
assumption of the power amplifier. The address is typically the
amplitude or power of S_{in} and is used to select a complementary
complex gain, S_{corr}, from correction (predistortion) tables 9 for
the digital sample in question. The correction tables 9 contain
the total complementary complex gain of the combination of the
analog predistorter 4 and power amplifier 5, such that the
combination of the complementary gain of the digital
predistorter 1, the analog predistorter 4 and the power
amplifier 5 results in linear gain and phase for all input
signal magnitudes. The complementary complex gain sample, S_{corr},
and the orignal input signal sample, S_{in}, are then processed
by a complex multiplier 10. The output of the complex multiplier
10, S_{out}, is designed to linearise the combination of the analog
predistorter and power amplifier. The signals used in Figure 4

are complex, which is indicated by the number 2 at the signal
paths.

Figure 5 illustrates an example of performing 3rd order analog RF
predistortion of the kind referred to by reference number 4 in
Figure 1. The digitally predistorted signal converted to RF
forms an input RF_{in} to the analog predistorter 4. The RF_{in} signal
is delayed, as indicated by block 11, to ensure that RF signal
and correction signals coincide at multipliers 13, 13'. The
delayed Rf_{in} signal is then split, indicated by block 12, into
two signals with quadrature phase, i.e. there is a 90 degree
phase shift between the two signals.

Both of the quadrature phase signals are then mixed by the
multipliers 13 and 13', respectively, with the correction
(predistortion) signals I_{corr} and Q_{corr}, respectively. These
signals, I_{corr} and Q_{corr}, represent the analog complementary
complex gain of the amplifier. The resulting mixed signals are
then phase combined in a hybrid combiner 14. The output of the
analog predistorter, RF_{out}, is designed to linearise the power
amplifier.

The correction signals, I_{corr} and Q_{corr}, are generated by first
squaring, as indicated by squaring function block 18, the input
signal RF_{in}, then filtering, as indicated by filtering function
block 19, away unwanted harmonics generated by the squaring
function 18, and finally multiplying, as indicated by two blocks
16, the filtered signal from function 19 with two third order
coefficients 17, 17'. The two third order coefficients
approximate the complementary complex gain of the amplifier. It
is obvious to those familiar with the state of the art that
higher order coefficients can be used to achieve better matching
of the complementary gain of the amplifier and that there are
many other examples of analog RF predistorters, some of which
are described in Mark Briffa, "Linearisation of RF Power
Amplifiers", PhD thesis, 1996, department of Electrical and
Electronic Engineering, Victoria University of Technology,

December 1996, Australia and the international patent
applications WO 99/45640 and WO 99/45638.

SIMULATION RESULTS

By solving the frequency conversion problems caused by the
digital predistortion process by splitting the performance
requirements between digital and analog presdistortion in a way
according to the invention, improved linearity is achieved,
compared to digital predistortion alone. The solution of the
invention also gives improved correction capabilities over all
frequency ranges compared to either digital or analog
predistortion techniques alone.

This can be shown through the following simulation results using
a WCDMA signal with a bandwidth of 4.096MHz. Digital
predistortion linearisation only with a given power amplifier is
first assumed with reference to Figure 6.

The adjacent channel performance, or linearity performance, of
the amplifier is defined as the ratio of the power of a signal
to the power of adjacent signal power, on either the lower or
the upper sides. The power is calculated by integrating the
energy over a bandwidth of 4.096 MHz. For the signal this is
shown as the area between the two vertical solid lines, and for
the adjacent signal this is shown as the area between the dotted
vertical lines.

The adjacent channel performance of the given amplifier alone
(shown dotted in Figure 6) is 35.8 dBc and 34.4 dBc for the
lower and upper adjacent channels respectively. Applying perfect
digital predistortion (the ideal complementary function of the
given power amplifier) with 0.6dB peak to peak amplitude ripple
in the frequency converter results in an adjacent channel
performance that (shown solid in Figure 6) is 59.2 dBc and 58.8
dBc for the lower and upper adjacent channels respectively. The
performance of the given power amplifier has been improved by

digital predistortion by 23.4 and 24.4 dB, however limited by
the amplitude ripple in the frequency converter.

In the next set of results, the given amplifier is first
predistorted by a RF analog predistorter. With reference to Fig.
7, the adjacent channel performance (shown dotted in Figure 7)
is 41.1 dBc and 40.6 dBc for the lower and upper adjacent
channels respectively. The analog predistorter has improved the
given power amplifier by 5.3 dB and 5.2 dB. Notice that the
analog predistorter has also improved the higher order
distortions (wider frequency range) of the amplifier in this
example.

Digital predistortion is now applied to the analog predistorter
and the given power amplifier. Perfect digital predistortion
(the ideal complementary function of the analog predistorter and
given power amplifier) with 0.6dB peak to peak amplitude ripple
in the frequency converter results in an adjacent channel
performance (shown solid in Figure 7) of 63.1 dBc and 62.8 dBc
for the lower and upper adjacent channels respectively.
Obviously the performance of the analog predistorter and given
power amplifier has been improved by a further 22 and 22.2 dB
with the addition of digital predistortion.

Notice that the overall performance improvement of digital
predistortion in both examples was 23-24 and 22dB. Given
measurement tolerances these values could be considered very
similar. Digital predistortion has therefore been limited in
performance by the ripple of the frequency upconverter,
regardless of the initial linear performance of the analog
parts. Additionally the overall performance improvement
generated by the combination of analog and digital predistortion
techniques is given by the sum of the individual improvements in
the region where both digital and analog predistortion is
active. This region is shown in Figures 6 and 7. The larger
frequency range over which only analog predistortion is active,
is not shown in Figures 6 and 7. However, the spectral

performance over the larger frequency range is also enhanced but to a lesser extent than that shown in Figures 6 and 7.

CLAIMS

1. A method for linearising a radio frequency power amplifier by
   predistortion, comprising the steps of
a) receiving a digitized base-band input signal, to be amplified
   by said amplifier,
b) performing digital predistortion on the received signal to
   compensate for amplifier distortion,
c) converting by means of two D/A converters the predistorted
   signal to an analog signal,
d) performing analog frequency conversion on the converted
   analog signal,
e) performing analog predistortion on the frequency converted
   signal,.
f) amplifying the analog predistorted signal by said amplifier.

2. A method for linearising a radio frequency power amplifier by
   predistortion, comprising the steps of
a) receiving a digitized base-band input signal, to be amplified
   by said amplifier,
b) performing digital predistortion on the received signal to
   compensate for amplifier distortion,
c) converting the digitally predistorted signal to a low
   intermediate frequency,
d) converting the signal to an analog signal via a D/A-
   converter,
e) performing analog frequency conversion to produce a radio
   frequency signal,
f) performing analog predistortion on the radio frequency
   signal,
g) amplifying the analog predistorted signal by said amplifier.

3. A method according to claim 1 or 2, comprising performing the
   step of analog predistortion adaptively by extracting an
   error signal component from the output of the amplifier to be
   used for adjusting the predistorted signal in accordance with
   error behaviour of the amplifier.

4) A method according to any of claims 1 - 3, comprising
   performing the step of digital predistortion adaptively by
   extracting an error signal component from the output of the
   amplifier and adjusting the predistortion signal in
   accordance with the error behaviour of the amplifier in
   real-time operation.

5) A method according to any of claims 1 - 4, comprising
   splitting the received baseband input signal into two signals
   having a phase difference of 90o and thereafter performing
   the steps of the respective preceding claims.

6) A power amplifier for linear amplification of radio frequency
   (RF) signals, comprising
   a) means for receiving a base-band input signal,
   b) means for performing digital predistortion on the input
      signal,
   c) means for D/A converting the predistorted signal,
   d) means for performing analog frequency conversion to achive
      a radio frequency signal,
   e) means for performing analog predistortion on the
      radio frequency signal,
   f) means for performing amplification on the signal of step
      e).

7) A power amplifier for linear amplification of radio
   frequency (RF) signals, comprising
   a) means for receiving a base-band input signal,
   b) means for performing digital predistortion on the input
      signal,
   c) means for converting the digitally predistorted signal to
      a low intermediate frequency,
   d) means for D/A converting the signal obtained by step c),
   e) means for performing analog frequency conversion to
      achieve a radio frequency (RF) signal,
   f) means for performing analog predistortion.
   g) means for performing amplification on the signal of step

f).

8) A power amplifier for linear amplification of radio
    frequency signals, comprising
    a) means for receiving a base-band input signal,
    b) means for splitting the received input signal into two
       signals having 90° phase difference,
    c) first and second path means for receiving each one of the
       two splitted signals obtained in step b), said first and
       second path means each including
       c1) means for digital predistortion of the respective
           signal,
       c2) means for D/A converting the signals obtained by step
           c1),
       c3) means for performing analog frequency conversion on
           the signals obtained by step c2),
       c4) means for performing analog predistortion on the
           signals obtained by step c3),
       c5) means for amplifying the signals obtained in step
           c4),
    d) means for combining the processed signals.

9) A power amplifier for linear amplification of radio
    frequency (RF) signals, comprising
    a) means for receiving a base-band input signal,
    b) means for splitting the received input signal into two
       signals having 90° phase difference,
    c) first and second path means for receiving each one of
       the two splitted signals obtained in step b), said
       first and second path means each including
       c1) means for digital predistortion of the respective
           signal,
       c2) means for converting the digitally predistorted
           signal to a low intermediate frequency,
       c3) means for D/A converting the signal resulting from
           step c2),
       c4) means for performing analog frequency conversion

on the signal resulting from step c3) for
producing a radio frequency signal,

c5) means for performing analog predistortion on the
signal resulting from step c4),
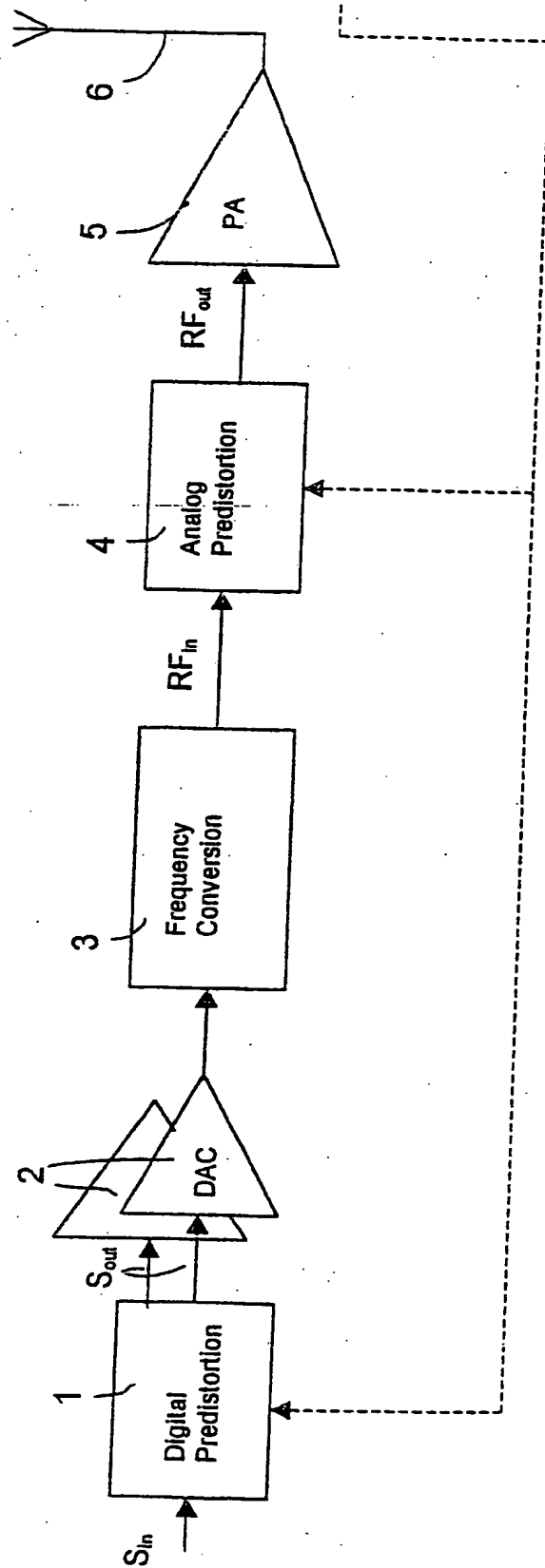
d) means for combining the processed signals.
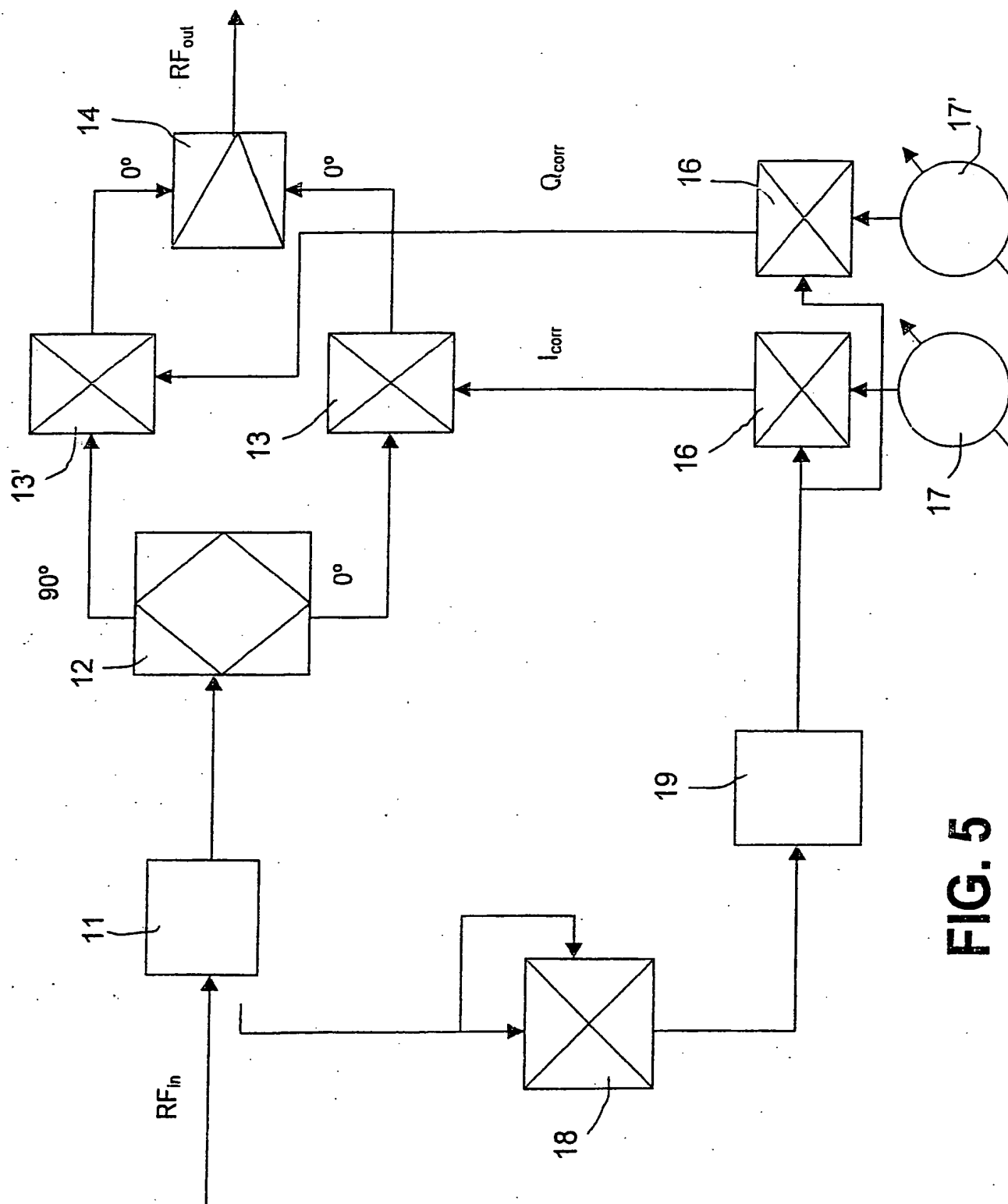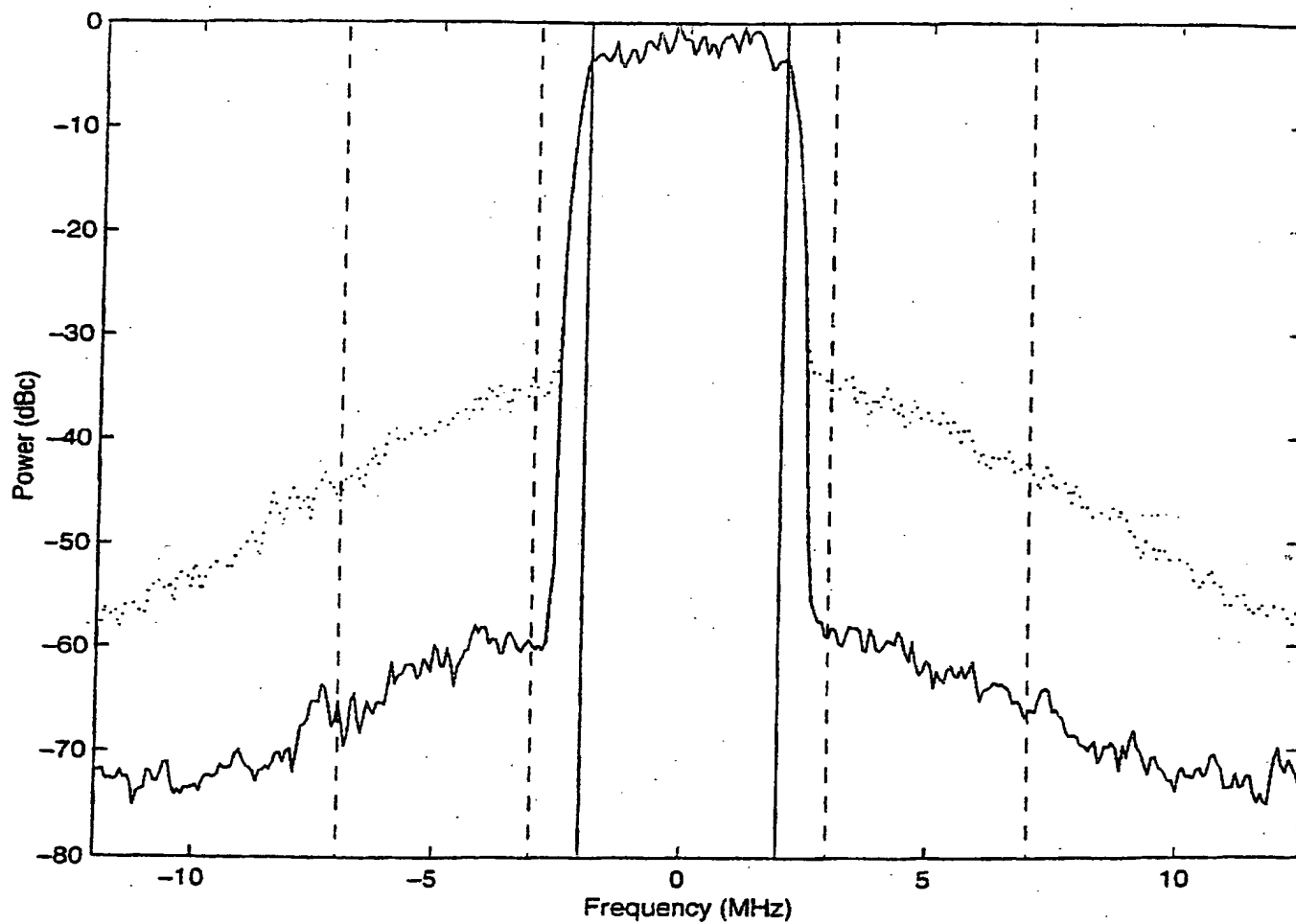
FIG. 1

FIG. 2
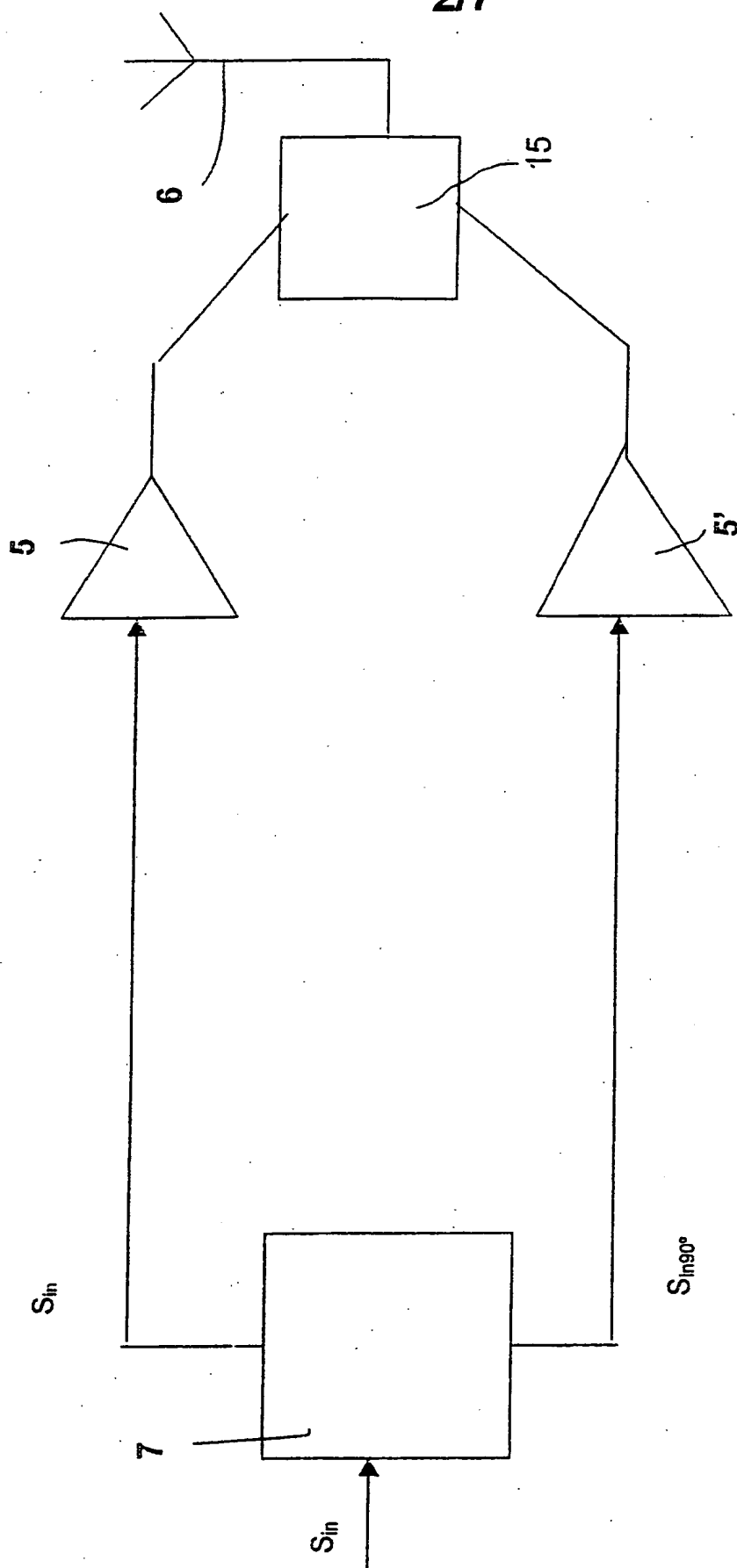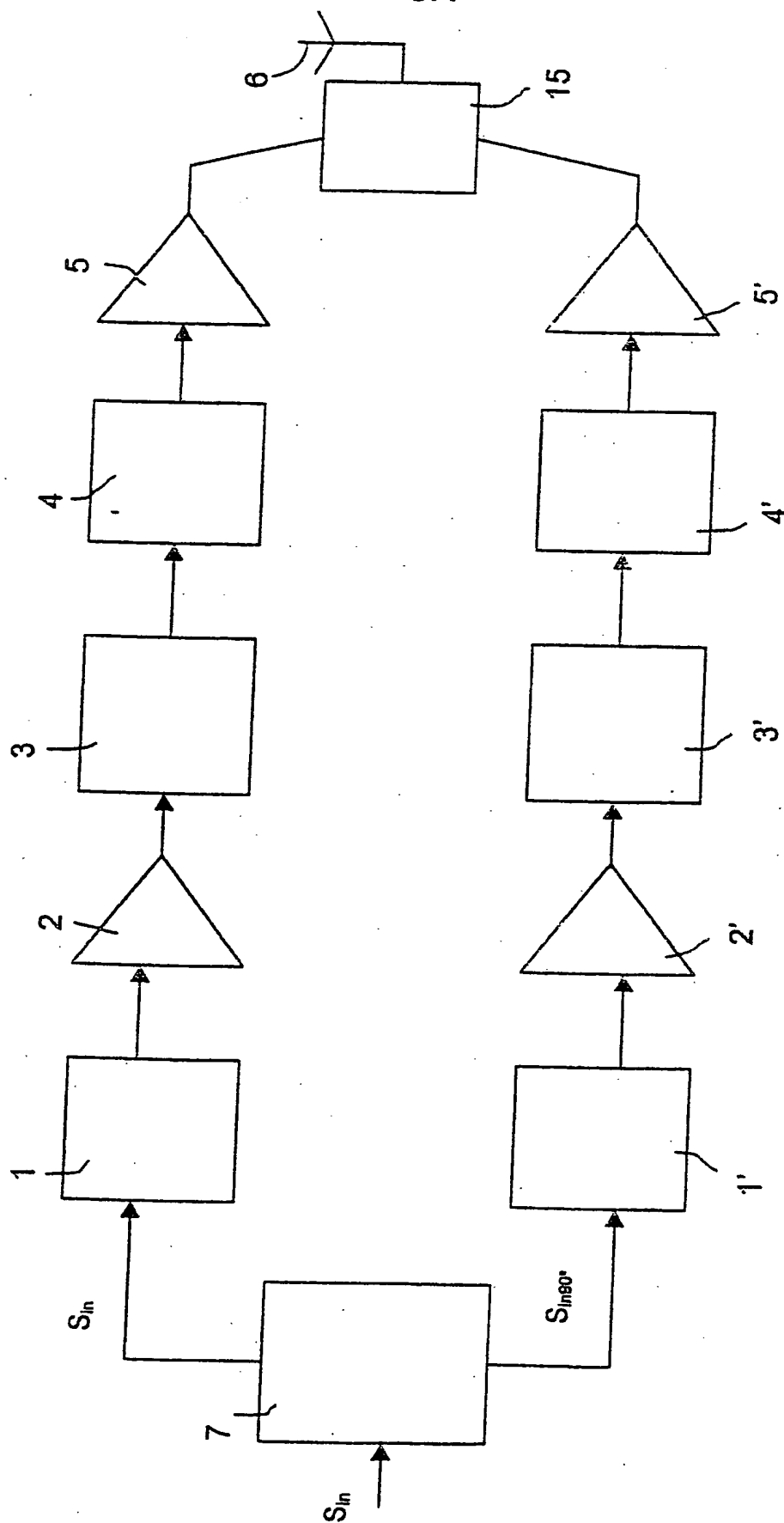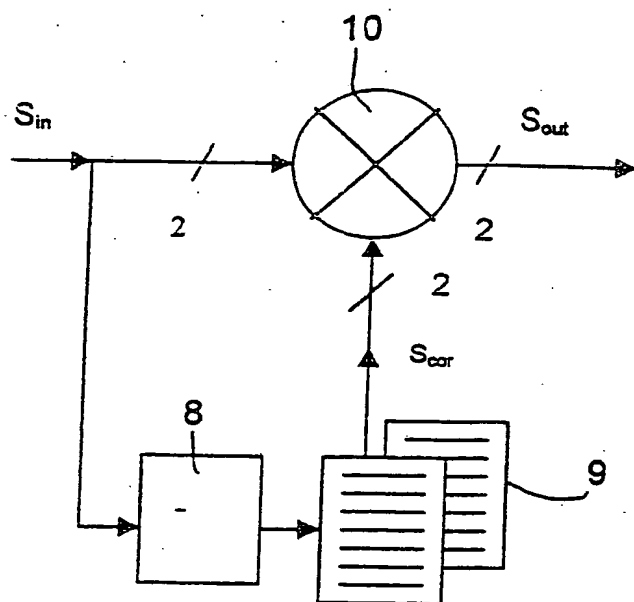
FIG. 3

FIG. 4

FIG. 5

FIG. 6
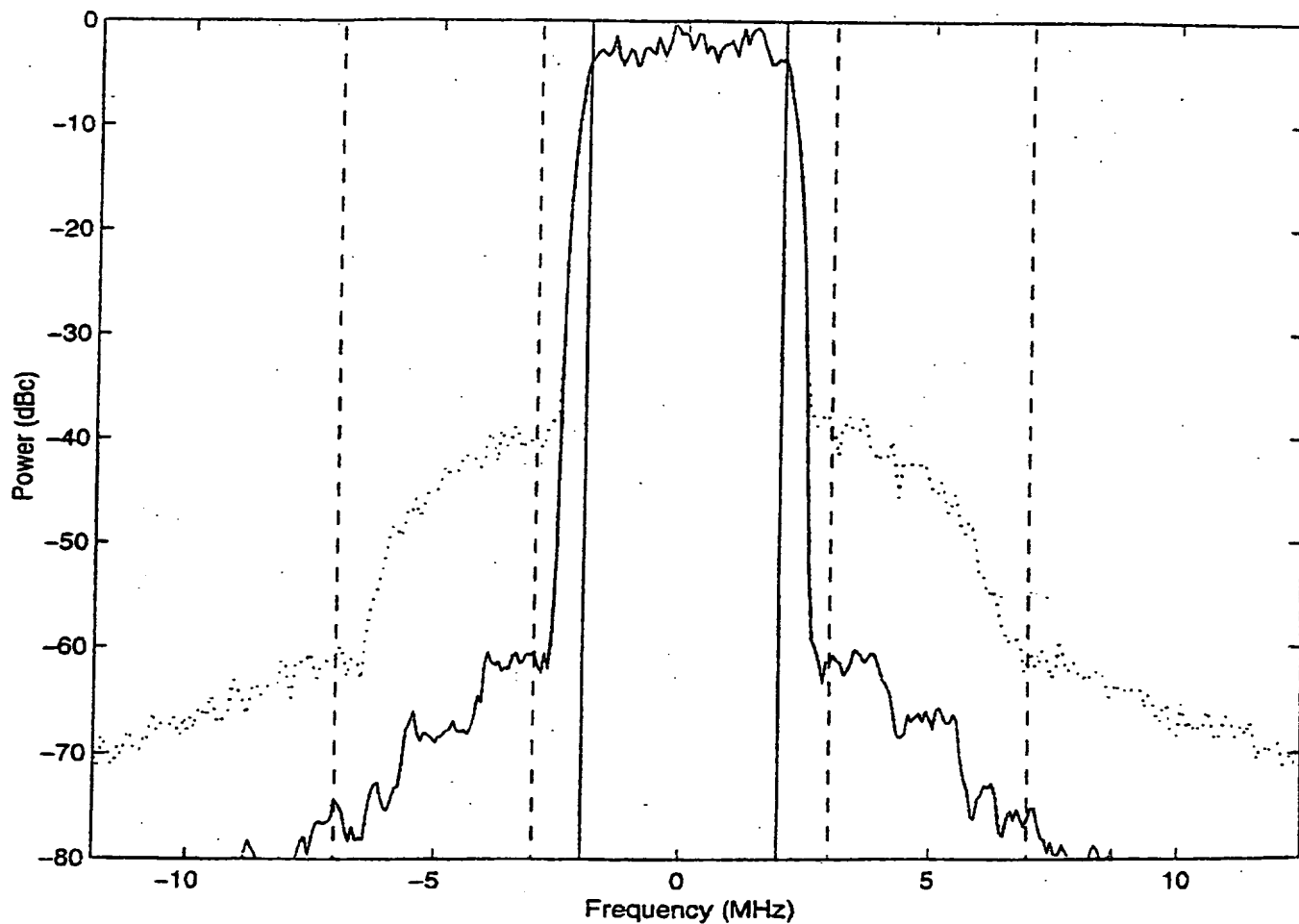
FIG. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H03F1/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 898 338 A (PROCTOR JAMES A ET AL) 27 April 1999 (1999-04-27)	1,3,4,6, 8
Y	the whole document ---	2,5,7,9
Y	US 4 291 277 A (BOYD ROBERT W ET AL) 22 September 1981 (1981-09-22)	2,5,7,9
A	the whole document ---	1,3,4,6, 8

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
7 March 2001	14/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040. Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Segaert, P

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			Inte ional Application No
			PCT/SE 00/02312

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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US 4291277	A	22-09-1981	NONE		